1) $Q = 0.8\ m^3/s$

Filter boxes $10m \times 20m$

$V = 110\ m^3/d \cdot m^2$

$$0.8\ \frac{m^3}{s} \times \frac{60s}{m} \times \frac{60\ m}{h} \times \frac{24\ h}{d} = 69{,}120\ \frac{m^3}{d}$$

$$N = 0.0195\,(Q)^{0.5} = 0.0195\,(69{,}120\ m^3/d)$$

$= 5.12$ filters so use 6 filter cells and 3 filter boxes.

Let the gullet width $= 0.6\ m$

$$10m - 0.6\ m = 9.4\ m \qquad \frac{9.4\ m}{2} = 4.7\ m/\text{cell}$$

Each cell is $20\ m \times 4.7\ m$

$L:W = 20:4.7 = 4.25:1$ range is 2:1 to 4:1

$$\frac{Q}{V} = \frac{69{,}120\ m^3/d}{110\ m^3/d \cdot m^2} = 628.4\ m^2$$

$$V = 110\ \frac{m^3}{d \cdot m^2} \times \frac{d}{24\ h} = 4.58\ \frac{m}{h} \qquad 5-12\ \frac{m}{h} \text{ normal range}$$

Need to assume the filter box dimensions exclude the gullet width.

Let each cell be $5m \times 20m$ or 4:1 o.k.

$$\frac{628.4\ m^2}{6\ \text{cells}} = \frac{104.7\ m^2}{\text{cell}} \quad ? \quad (5\ m \times 20\ m) = 100\ m^2$$

This is not quite enough and there is no redundant cell

1) continued.

Use 8 filter cells in 4 filter boxes.

With 1 cell out of operation:

$$\frac{69{,}120 \; m^3}{700 \; m^2 \;\; d} = 98.74 \; \frac{m}{d} < 110 \; \frac{m^3}{d \cdot m^2}$$

The 7 cells are able to handle the flow within the hydraulic loading rate.

2) Depth = 0.75 m

V_a = 230 $m^3/d \cdot m^2$ = 0.00266 m/s

SG_{sand} = 2.80

ϕ = 0.80

ε = 0.40

T = 5°C ; $\nu = 1.519 \times 10^{-6}$ m/s

Sieve no.	% Ret.	d_g (m)	Re	C_D	h_L, m
8-12	0.00				
12-16	0.40	0.00141	1.98	14.59	0.001165
16-20	13.10				
20-30	54.50	0.000704	0.9862	24.34	0.531
30-40	30.20				
40-50	1.785	0.000353	0.4945	48.53	0.06916
50-70	0.015				
	100.0				

#12 is 1.68 mm #16 is 1.19 mm

geometric mean dia. $d_g = (d_1 d_2)^{0.5}$

$= (1.68 \times 1.19)^{0.5}$

$= 1.41$ mm $= 0.00141$ m

$$Re = \frac{\phi d V_a}{\nu} = \frac{(0.8)(0.00141)(230\ m^3/d \cdot m^2)}{(1.519 \times 10^{-6}\ m/s)(86{,}400\ s/d)} = 1.98$$

$$C_D = \frac{24}{Re} + \frac{3}{\sqrt{Re}} + 0.34 = 12.12 + 2.13 + 0.34 = 14.59$$

h_L for this layer separately $= \dfrac{1.067 (V_a)^2 (D) C_d}{\phi g (\varepsilon)^4 d_g}$

$$h_L = \frac{(1.067)(0.00266\ m/s)(0.00266\ m/s)(0.004)(0.75\ m)(14.59)}{(0.80)(9.81\ m/s^2)(0.40)^4\ (0.00141\ m)}$$

$$= \frac{3.30 \times 10^{-7}}{2.832 \times 10^{-4}} = 0.001165\ m$$

2) continued

\# 20 is 0.841 mm ; # 30 is 0.590 mm

$$d_g = (0.841\ mm \times 0.590\ mm)^{0.5} = 0.704\ mm = 0.000704\ m$$

$$Re = \frac{\phi d V_a}{\nu} = \frac{(0.8)(0.000704\ m)(0.00266\ m/s)}{(1.519 \times 10^{-6}\ m/s)}$$

$$= 0.9862$$

$$C_D = \frac{24}{Re} = 24.34$$

$$h_L \text{ for this layer} = \frac{1.607\ (V_a)^2\ D\ C_d}{\phi\ g\ (\varepsilon)^4\ d_g}$$

$$h_L = \frac{1.067\ (0.00266\ m/s)^2\ (0.545)(0.75\ m)(24.34)}{(0.80)(9.81\ m/s^2)(0.40)^4\ (0.000704\ m)}$$

$$= \frac{7.5111 \times 10^{-5}\ m}{1.4144 \times 10^{-4}} = 0.531\ m$$

\#40 in 0.420 mm; #50 is 0.297 mm; $d_g = 0.353$ mm

$$Re = \frac{0.8\ (0.000353\ m)(0.00266\ m/s)}{1.519 \times 10^{-6}\ m/s} = 0.4945$$

$$C_d = \frac{24}{Re} = \frac{24}{0.4945} = 48.53$$

$$h_L = \frac{1.067\ (0.00266\ m/s)^2\ (0.01785)(0.75\ m)(48.53)}{(0.80)(9.81\ m/s)(0.40)^4\ (0.000353)}$$

$$= \frac{4.905 \times 10^{-6}}{7.092 \times 10^{-5}} = 0.06916\ m$$

3) $D = 0.75\ m$

$V_a = 230\ m^3/d \cdot m^2 = 0.00266\ m/s$

$SG_{sand} = 2.80$

$\varepsilon = 0.4$

$T = 5°C$

$\rho = 999.967\ kg/m^3$

$\rho_{sand} = (2.80)(999.967\ kg/m^3) = 2800\ kg/m^3$

$\gamma = 9.807\ kN/m^3$

$\gamma_{sand} = (2.80)(9.807\ kN/m^3) = 27.46\ kN/m^3$

$\mu = 1.519 \times 10^{-3}\ Pa \cdot s = 1.519\ mPa \cdot s$

Sieve no.	% Retained	% Finer	d_g, m
8 - 12	0.00	100	
12 - 16	0.40	100	0.00141
16 - 20	13.10	99.6	0.00100
20 - 30	54.50	86.5	0.000704
30 - 40	30.20	32	0.000498
40 - 50	1.785	1.80	0.000353
50 - 70	0.015	0.015	0.000250

#16 is 1.19 mm; #20 is 0.841 mm; $d_g = 1.000$ mm

#30 is 0.590 mm; #40 is 0.420 mm; $d_g = 0.4978$ mm

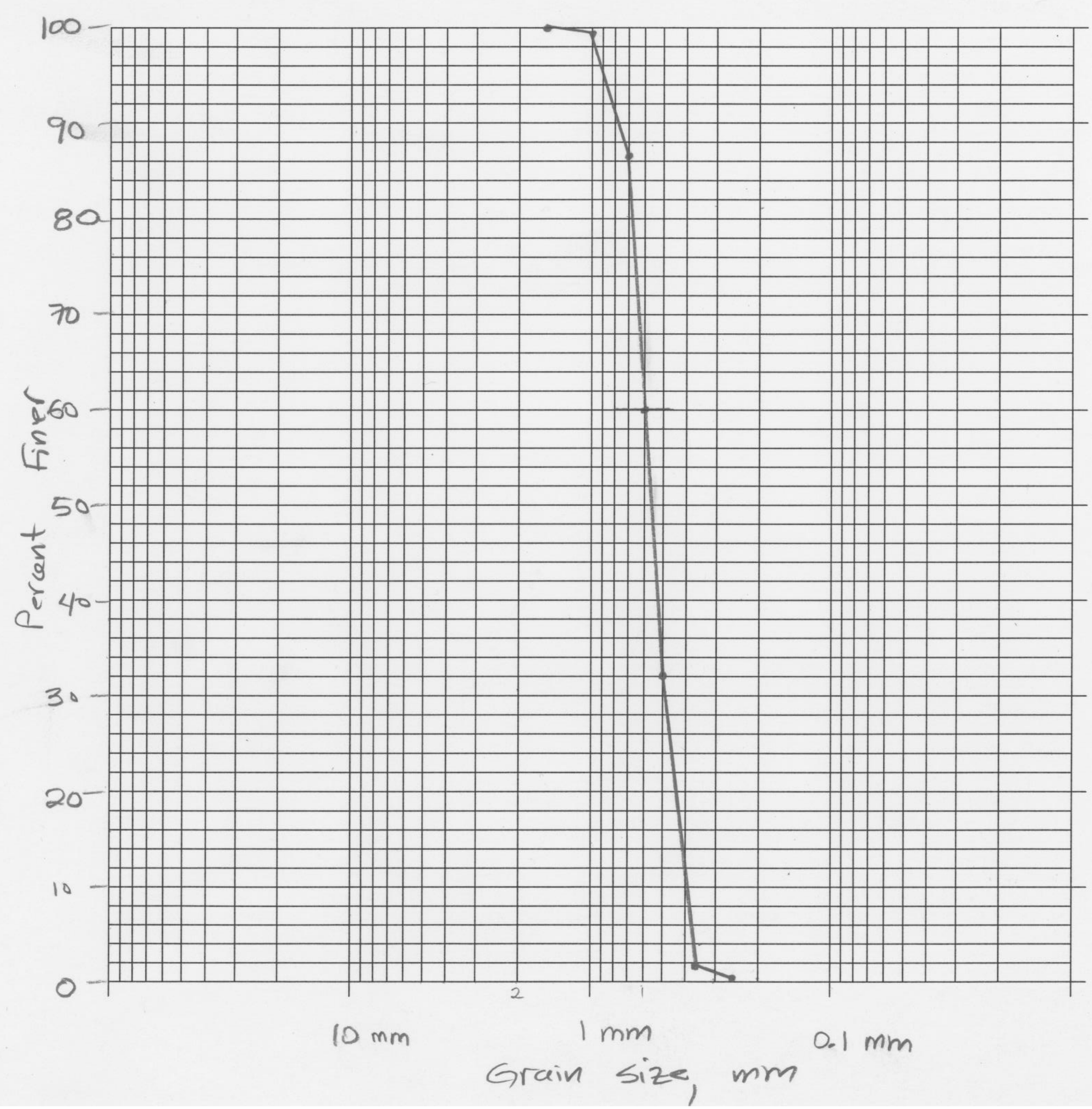
#50 is 0.297 mm; #70 is 0.210 mm; $d_g = 0.250$ mm

Plot percent finer on semi-log paper (next page)

From graph $d_{60} = 0.60$ mm

or simply interpolating between 86.5% and 32% to get the 60% finer size gives 0.604 mm $\approx$ 0.60 mm.

⑥



100
90
80
70
60
50
40
30
20
10
0
Percent Finer
2
1
10 mm
1 mm
0.1 mm
Grain size, mm

3) continued.

$$V_f = \frac{0.0000839\,(d_{60})^{1.82}\left[\gamma(\gamma_{sand} - \gamma)\right]^{0.94}}{\mu^{0.88}}$$

$$V_f = \frac{0.0000839\,(0.60)^{1.82}\left[9.807\,(27.46 - 9.807)\right]^{0.94}}{(1.519)^{0.88}}$$

$$= \frac{0.0000839\,(0.3947)[127.07]}{1.4447}$$

$$= 0.002913 \text{ m/s}$$

$$Re_f = \frac{\rho V_f d_{60}}{\mu} = \frac{(999.967\text{ kg/m}^3)(0.002913\text{ m/s})(0.0006\text{ m})}{0.001519\text{ Pa}\cdot\text{s}}$$

$$= 1.1506 \qquad \left(Pa = \frac{N}{m^2} = \frac{kg\cdot m}{s^2\cdot m^2}\right)$$

$Re_f \le 10$ so K_R not needed

$$V_s = 8.45\,V_f = (8.45)(0.002913\text{ m/s}) = 0.0246\text{ m/s}$$

$$Re_o = \frac{\rho V_s d_{60}}{\mu} = 8.45\,Re_f = 9.722$$

$$n_e = 4.45\,Re_o^{-0.1} = 4.45(9.722)^{-0.1} = 3.5447$$

$$V_f = K_e(\varepsilon)^{n_e}; \quad K_e = \frac{V_f}{(\varepsilon)^{n_e}} = \frac{0.002913\text{ m/s}}{(0.4)^{3.5447}} = 0.075\text{ m/s}$$

The smallest particle that cannot be washed out by backwashing is 0.00025 m or 0.250 mm

From Fig. 8.7, estimated settling velocity is about 0.034 m/s $= V_b$

3) continued

$$V_b = K_e (\varepsilon_e)^{n_e}$$

$$\varepsilon_e = \left(\frac{V_b}{K_e}\right)^{1/n_e} = \left(\frac{0.034 \text{ m/s}}{0.075 \text{ m/s}}\right)^{1/3.5447} = 0.45\dot{3}^{\,0.2821}$$

$$= 0.800$$

$$D_e = \frac{D(1-\varepsilon)}{1-\varepsilon_e} = \frac{0.75(1-0.4)}{1-0.8} = \frac{0.45}{0.2} = 2.25 \text{ m}$$